Laboratory Evaluation to Study the Engineering Behavior of Slag Cement for Soil Subgrade

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***Abstract*-- This study aimed to improve the existing local soil using Portland slag cement (PSC) as a soil stabilizer. PSC is a cement manufactured from blast furnace slag, an industrial waste product from blast furnaces. As per IS 455:1989, PSC is a cement which has physical properties similar to those of ordinary Portland cement and has low heat of hydration and is relatively better resistant to soils and water containing excessive amounts of sulphates of alkali metals, alumina and iron, as well as to acidic waters. In the present study, PSC was used as a chemical additive, and its physical and chemical properties are compared with ordinary Portland cement (OPC). The laboratory study was undertaken to evaluate the efficacy of PSC as a soil stabilizer along with three different types of soil.**

Present investigation revealed that admixing of PSC improves the California Bearing Ratio (CBR) value and Unconfined Compressive Strength (UCS) value for all the three types of soil. The rate of increase of CBR value is apparently linear with the per cent content of PSC and relatively higher UCS values are observed for PSC admixed soil samples in comparison to natural soil samples.

Based on the findings of present laboratory study, it is inferred that PSC has the adequate potential for use as a soil stabilizer.

***Index Terms* – Ordinary Portland cement, Portland slag cement, soil stabilization.**

I. INTRODUCTION

STABILIZED soil is, in general, a composite material that results from combination and optimization of properties in individual constituent materials. Well-established techniques of soil stabilization are often used to obtain geotechnical materials improved through the addition into soil of such cementing agents as ordinary Portland cement (OPC), lime, asphalt, etc. Replacement of natural soils, aggregates, and cement with solid industrial by-product is highly desirable. In some cases, a by-product is inferior to traditional earthen materials. Due to its lower cost, however, it makes an attractive alternative if adequate performance can be obtained. In other cases, a by-product may have attributes superior to those of traditional earthen materials.

Often selected materials are added to industrial by-products to generate a material with well-controlled and superior properties. This paper presents laboratory results for a sandy, clayey and silty soils stabilized with PSC, which is cement manufactured from blast furnace slag, an industrial waste product from blast. The results obtained were compared with that of soil stabilized with OPC. PSC has cementing properties and has proven to be an effective stabilizing agent for different soils.

II. EARLIER STUDIES

Previous studies on soil stabilization have focused on the use of Portland cement and other cementatious materials like pulverised fuel ash and lime (Conner and Hoeffner, 1998; Shi and Spence, 2004). However, there is need to promote sustainable reuse of industrial by-products like ground granulated blast furnace slag (GGBS) cement in soil stabilization. The granulated slag is dried and then ground to a very fine powder, which is GGBS (Higgins, 2005). GGBS has been utilised in many cement applications to provide enhanced durability, high resistance to chloride penetration and resistance to sulphate attack. It has also been used together with lime in ground improvement works where its incorporation into the blend is very effective in combating the expansion associated with the presence of sulphate or sulphide in the soil (Higgins, 2005). The work of Akhter et al. (1990) documented positive effects on the use of both binder formulations in reducing the leachability of As, Cd, Cr and Pb, while Allan and Kukacka (1995) showed that slag-cement successfully stabilised Cr in toxicity characteristic leaching procedure (TCLP) tests. The advantages of a well-proportioned mix of slag-cement include higher early and later strengths than Portland cement (CEMI) and better resistance in aggressive environments like immersion in water, acidic and sulphate solutions. It has been reported that heavy metals show much less interference with the hydration of slag-cement than with Portland cement. Further, the leachability of some contaminants (for e.g. As, Cr, Cu and Pb) from slag-cement stabilised hazardous and radioactive wastes is lower than that from Portland cement stabilised wastes (Shi and Jimenez, 2006). The strength of slag-cement depends on the mix proportion. The higher the replacement levels of GGBS in the mix, the lower the early strength. The optimum proportion of GGBS for maximum strength of slag-cement is between 50 and 60% of the total binder dosage (Khatib and Hibbert, 2005; Oner and Akyuz, 2007). Similarly, an optimum amount of lime is required for full hydration and pozzolanic reactions of lime-slag and for high strength, the amount of GGBS in the blend should be greater than the amount of lime. The optimum proportion for maximum strength is about one part lime and four parts GGBS (Higgins, 2005). Cement reactions were found to continue beyond a 28 day curing time, which is a standardised curing period within the cement and concrete industries. Since hydration continues, there may be changes in release rates of contaminants from the treated material beyond this period and these must be considered when evaluating leaching data (Bone et al., 2004). In addition, it is believed that the base exchange and cementing action of Portland cement with clay is similar to that of lime (Croft, 1967; Chen, 1975; Kezdi, 1979). Cement in soil stabilization increases the strength of the mixture. In fact, in clay soils the chemical reaction of cement and soil is responsible for soil improvement. The hydration process of two major elements of cement produces CSH and lime, which are two new products in this process. Therefore, the interaction between this lime and clay minerals may also play an essential role in terms of the soil cement interaction process. The mechanism of the latter will be the same as that of a lime–clay interaction, as previously addressed (Yong et al., 1996; Bahar et al., 2004; Al-Rawas et al., 2005; Aiban et al., 2006).

III. MATERIALS USED

1) Soil:

Three types of soil, referred to as soils S_1, S_2 and S_3 are used for this study. Soil S_1 is silty sand (A-3), soil S_2 is silty soil of low compressibility (A-2-4), and soil S_3 is clay of low compressibility (A-6). The index properties such as liquid limit, plastic limit, plasticity index and other important soil properties as per AASHTO and United States soil classification systems are presented in Table I. Fig. 1 presents the grain size distribution curves of these soils.

TABLE I
PHYSICAL PROPERTIES OF DIFFERENT SOILS

Properties	Soil S_1	Soil S_2	Soil S_3
Optimum moisture content (%)	11.00	14.00	18.00
Dry density (gm/cc)	1.885	1.764	1.670
Specific gravity	2.43	2.24	2.18
Liquid limit (%)	–	26	35
Plastic limit (%)	–	18	21
Plasticity index	–	8	14
Coefficient of uniformity	2.67	–	–
Coefficient of curvature	1.25	–	–
Unified soil classification	SM	ML	CL
AASHTO soil clasification	A-3	A-2-4	A-6
Type of soil	Silty sand	Silty soil of low compressibility	Clay of low compressibility

2) Cement:

The Portland slag cement (PSC) obtained from by-product from steel industry was used for stabilizing the three types of soil S_1, S_2 and S_3. For comparison study, OPC was also considered as a soil stabilizer. The physical and chemical properties of OPC & PSC are given in Table II and Table III respectively.

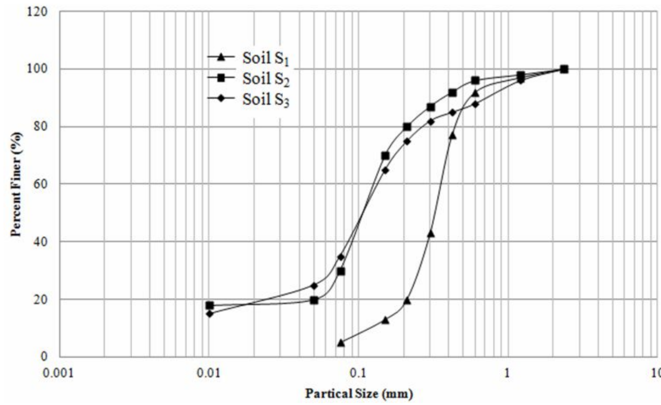

Fig. 1. Particle Size Distribution of Soils

TABLE II
PHYSICAL PROPERTIES OF CEMENT

Properties	OPC	PSC
Specific gravity (gm/cm^3)	3.13	3.05
Fineness Surface area (m^2/kg)	300	280
Setting Time		
Initial (min)	130	150
Final (min)	235	255
Compressive Strength (kg/cm^2)		
3 days	213	141
7 days	229	198
28 days	441	335

TABLE III
CHEMICAL PROPERTIES OF USED CEMENT

Constituents	OPC Percentage by weight (%)	PSC Percentage by weight (%)
Ignition loss	1.32	2.13
SiO_2	20.4	25.7
Al_2O_3	8.21	8.9
Fe_2O_3	2.56	1.84
CaO	63.21	55.42
MgO	3.5	3.4
SO_3	2.6	2.7

IV. LABORATORY INVESTIGATIONS

Influence of PSC and OPC on the geotechnical characteristics of different types of soil were investigated by conducting the various laboratory tests viz. standard proctor compaction test, California bearing ratio (CBR) test and unconfined compression test (UCS). The tests were performed for various combinations of soil-PSC and soil-OPC mixtures as presented in Table IV.

TABLE IV
DETAILS OF SOIL-CEMENT COMBINATIONS

No. of trials	Percentage of soil type (S_1, S_2 and S_3)	Variation of PSC	Variation of OPC
1	100%	0 %	0%
2	99%, 98%, 97%, 96%	1%, 2%, 3%, 4%	0 %, 0 %, 0 %, 0 %
3	99%, 98%, 97%, 96%	0%, 0%, 0%, 0 %	1%, 2%, 3%, 4%

Standard Proctor Test: The geotechnical properties of soil (shear strength, CBR, permeability, etc.) are dependent on the moisture and density at which the soil is compacted. Generally, a high level of compaction of soil enhances the geotechnical parameters of the soil, so that achieving the desired degree of relative compaction necessary to meet specified or desired properties of soil is very important. The aim of the Proctor test (moisture-density) was to determine the optimum moisture contents and dry densities of both untreated compacted soil and treated soil-mixtures. In order to obtain these parameters, heavy compaction test was employed as per IS: 2720 (Part 8). The obtained test results are presented in Figs. 2 to 7.

California Bearing Ratio Test: The California bearing ratio (CBR) is a penetration test for evaluation of the mechanical strength of road sub-grade and base courses. This test was conducted after 4 days of soaking in water as per IS: 2720 (Part 16). The results revealed from the laboratory study are presented in Figs. 8 to 10.

Unconfined Compression Test: Unconfined compression test was conducted on natural and admixed soil samples as mentioned in Table IV according to IS: 2720 (Part 10)-1973. The unconfined compressive test is a special form of a triaxial test in which the confining pressure is zero. The unconfined compressive strength of soil is considered as an important parameters for pavement design, hence three samples have tested for each mixture at the strain rate of 0.05 inch/min. The results obtained from the unconfined compression test have worked out; stress-strain curves, variation of unconfined compressive strength with percent stabilizers were also worked out. Their results in the form of bar chart are presented in Figs. 11 to 13.

V. RESULTS AND DISCUSSION

1) *Standard Proctor Test*

When OPC & PSC are admixed with soils, S_1 & S_2 at an equal interval of 1% up to 4%, the moisture content decreases gradually with an increase in additive contents in both cases (Fig. 2). However the soil sample that contain OPC showed higher moisture content between 2% and 4% additive content in comparison to PSC admixed soil samples. This behavior is mainly attributed to higher surface area of OPC in comparison to PSC. On other hand, admixing of 3% PSC and OPC with soil S_1 leads to reduction in moisture content up to 18% & 9% respectively. Maximum variation of moisture content between OPC and PSC admixed soil samples were observed at 3% admixing. However, same moisture content was read at 4% admixing for both OPC & PSC (Fig. 2). Similarly admixing of OPC & PSC with soil S_2 also showed reduction in moisture content and this reduction is more pronounced at 3% admixing, after which , it stabilized (Fig. 3).

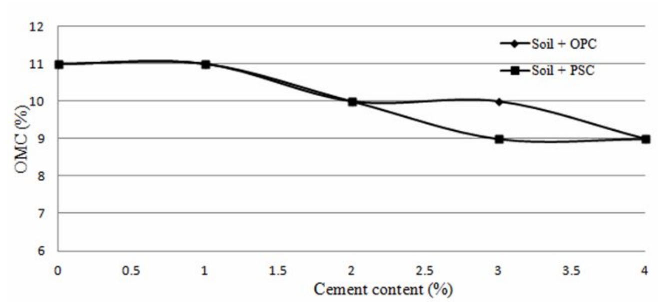

Fig. 2. OMC of admixed soil S_1

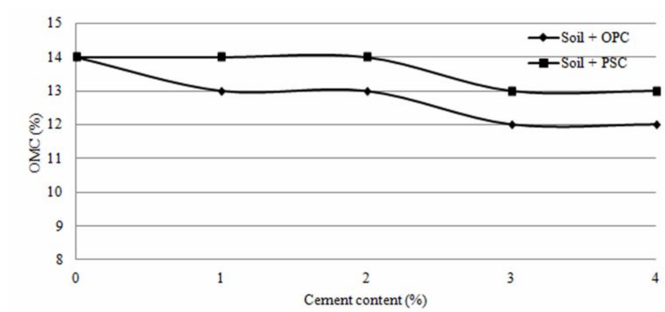

Fig. 3. OMC of admixed soil S_2

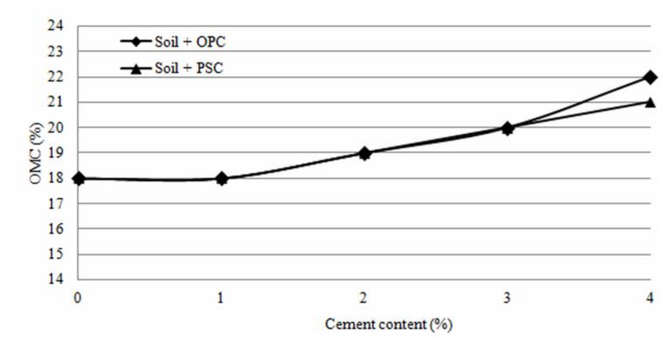

Fig. 4. OMC of admixed soil S_3

The finding of moisture content is quite contrary for soil S_3 when compared to soils S_1 and S_2. The moisture content increases as the dosages of OPC & PSC increases. Remarkable increased of moisture content was observed after 2% admixing for both cases (Fig. 4). The rate of increase of moisture content was maintained same up to 3% additive content. This increase was about 11% higher than that of natural soil samples.

The reduction in moisture content may be attributed to partial amount of water taken up by cement particles for chemical reaction; and increase in moisture content in soil S_3 is likely due to increase in plasticity limit of the soil, thereby a corresponding increase in moisture content. However, further investigation is suggested in this regard.

The natural soil samples S_1, S_2 & S_3 showed maximum dry densities of 1.885g/cc, 1.764g/cc & 1.670g/cc respectively. These density increases with the increase of additive contents especially for soil samples S_1 & S_2. This increase is more pronounced at 4 % additives content followed by 3%, 2% and 1% respectively. The rates of increase of densities are apparently linear with the additive contents when PSC is admixed with soil samples S_1 & S_2 (Figs. 5&6). However, this increase is sluggish after 3% additive content for soil sample S_1, whereas for soil S_2 remarkable increased of density is observed (Fig.6). Fig. 7 shows the patterns of decreasing of dry densities for soil sample S_3.

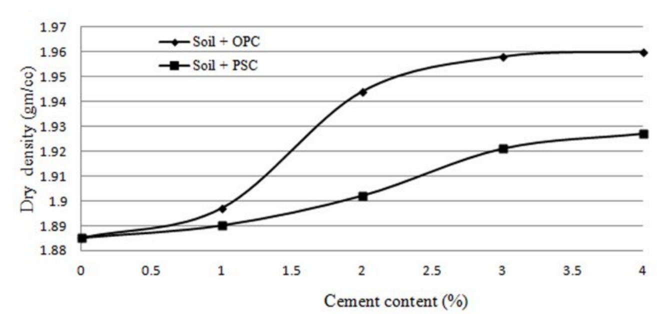

Fig. 5. MDD of admixed soil S_1

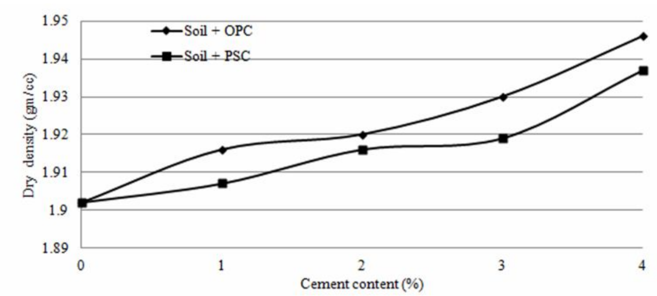

Fig. 6. MDD of admixed soil S_2

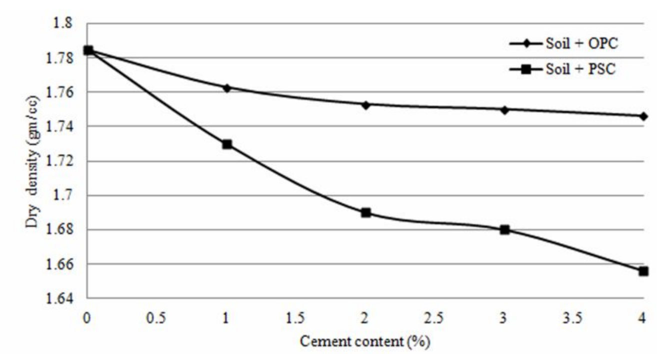

Fig. 7. MDD of admixed soil S_3

The rate of reduction of density is gradual for OPC admixed soil samples having maximum reduction of about 2 percent at 4% additive content with respect to density of natural soil. Whereas this reduction is more significant for PSC admixed soil sample having maximum reduction of about 6.9% with respect to density of natural soil sample.

2) California Bearing Ratio Test

The CBR is one of the common tests used to evaluate the strength of stabilized soils. Figs. 8 to 10 show the variation of CBR with increase in additives from 0 to 4 %. Admixing of both OPC and PSC showed marked improvement in the CBR compared to the CBR value of 5%, 7.5% and 4.6% for the natural soil samples S_1, S_2 and S_3 respectively. The rates of increase of CBR values are apparently linear with additive contents for all the cases except for OPC admixed soil sample S_1. The improvement of CBR values resulted from the reaction between the lime liberated from hydration reaction of cement. This reaction also contributed to interparticle bonding.

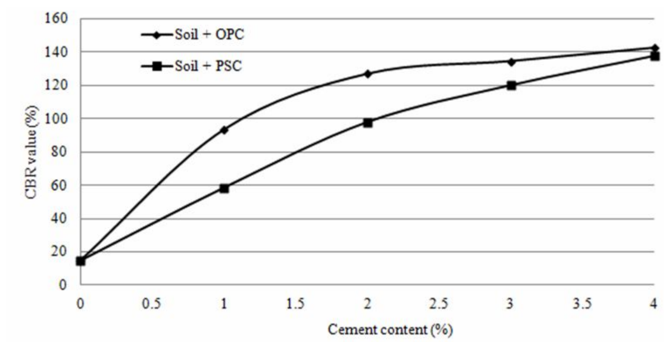

Fig. 8. CBR of admixed soil S_1

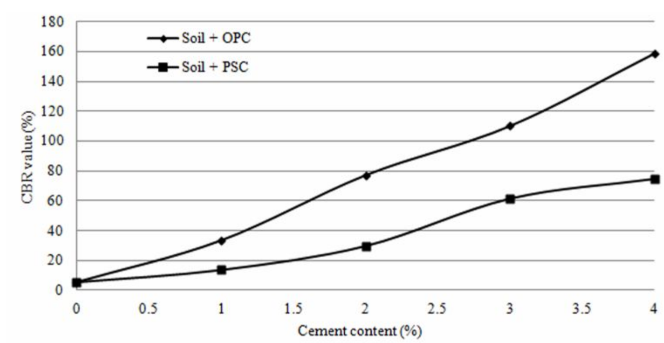

Fig. 9. CBR of admixed soil S_2

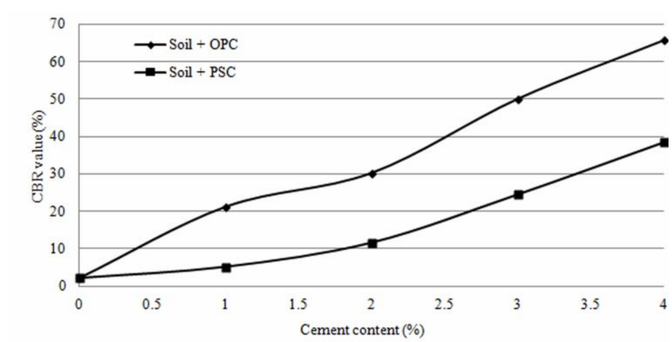

Fig. 10. CBR of admixed soil S_3

3) Unconfined Compressive Strength Test

Unconfined compression strength is the main test recommended for the determination of the required amount of additive to be used in the stabilization of soil.

Figs. 11 to 13 show the variation of UCS with increase in additives from 0% to 4% for 7 days, 14 days and 28 days curing period. Admixing of both OPC and PSC with natural soil showed considerable improvements in the UCS. The UCS improvement is related from the pozzolanic reaction between the lime liberated from the hydration reaction of cement in presence of moisture which ultimately could provide stronger bonding between the soil particles.

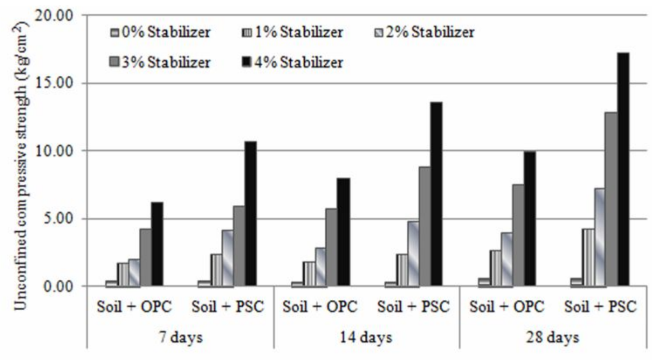

Fig. 11. UCS of admixed soil S_1

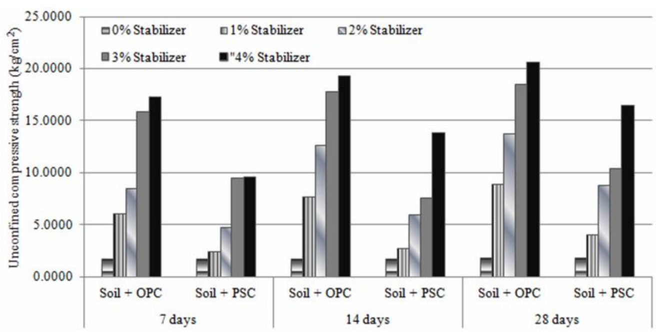

Fig. 12. UCS of admixed soil S_2

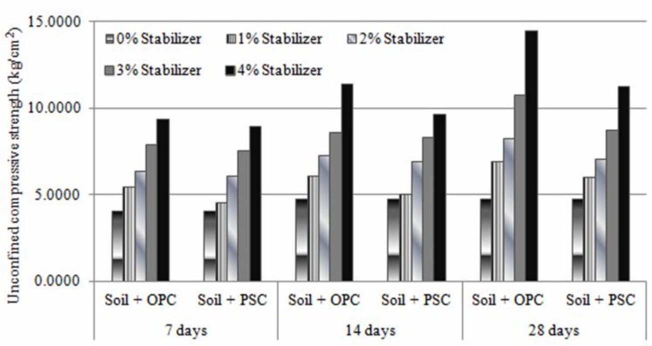

Fig. 13. UCS of admixed soil S_3

The amount of PSC will depend on the type of soil, design requirements, and overall economic considerations. The main motive behind of the present study is to evaluate the efficacy of the PSC in comparison to OPC. However, in the present study, incorporation of 2% PSC with soil S_1 could produce 150% equivalent strength of soil-cement stabilized mix as specified in IRC: 50. Therefore, the optimum dosage of PSC for soil S_1 may be taken as 2% by weight of dry soil. Whereas, for soil sample S_2, only about 46% equivalent strength is achieved at 2% admixing of PSC with soil. Therefore, higher dosage of PSC would be required in this case. Similarly, in the case of soil S_3, it could produce only about 18.46% equivalent strength hence, higher dosage of PSC may be suggested subject to confirmation of strength development at the later age because slag cement generally produces soil cement with lower early age strength and higher strength at later ages.

VI. CONCLUSION

1. The physical and chemical properties of PSC as tested in laboratory, confirms the standards required as per IS 455:1989, and makes PSC suitable for soil stabilization.
2. Soils S_1 and S_2 showed reduction in moisture contents when both OPC & PSC are admixed with. Whereas, this moisture was found to be in increasing order for soil S_3. The reduction of moisture content may be attributed to partial amount of water taken up by cement particles for hydration; and the increase of moisture content of soil S_3 is likely due to increase in plasticity limit of the soil, thereby a corresponding increase in moisture content. However, further investigation is suggested in this regard.
3. Admixing of both OPC and PSC with natural soil S_1 and S_2 showed improvements in dry densities. This improvement is more pronounced at 3% additives content for both cases and beyond 3%; the rate of increase of densities are sluggish. Whereas, for soil S_3, admixing of both OPC and PSC leads to reduction in dry densities. Admixing of cement at times results decreased in density where compared to natural soil although this factor is not significant when considering the physical characteristics of the mix, since cement in soil-cement mix, if cured in the presence of moisture, will hydrate much as it does in concrete.
4. Admixed soil samples produced substantially high UCS irrespective of per cent of additive contents for all days of curing (7, 14 & 28). The increase of UCS is comparatively higher for OPC as compared to PSC admixed soil samples. Similarly, higher CBR value was observed for OPC and PSC admixed soil samples in comparison to natural soil samples. The increased in CBR & UCS for the cement stabilized soils are due to the pozzolanic reaction taken placed between the cement grains & soil particles in presence of moisture resulting stronger bond between the soil particles.
5. OPC is costing approximately 4.5 times more than that of PSC, use of PSC as a soil stabilizer in place of OPC would be cost effective to approximately 4 to 5 times than that of OPC.
6. One of the limitation of PSC is the slow rate of hydration, hence prolong curing is mandatory. In addition, as this material is not available in abundant quantity in comparison to OPC, its utilization is limited to the vicinity of blast furnace plants.
7. Based on the findings from the present laboratory study, it is inferred that the PSC has the adequate potential for use as a soil stabilizer as OPC, therefore, PSC can be recommended as an effective soil stabilizer in place of OPC where it is easily available in abundant quantities.

VII. REFERENCES

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